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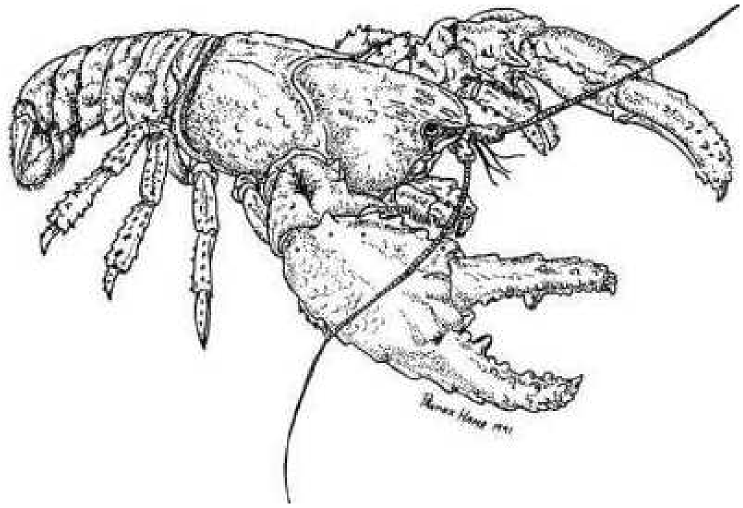
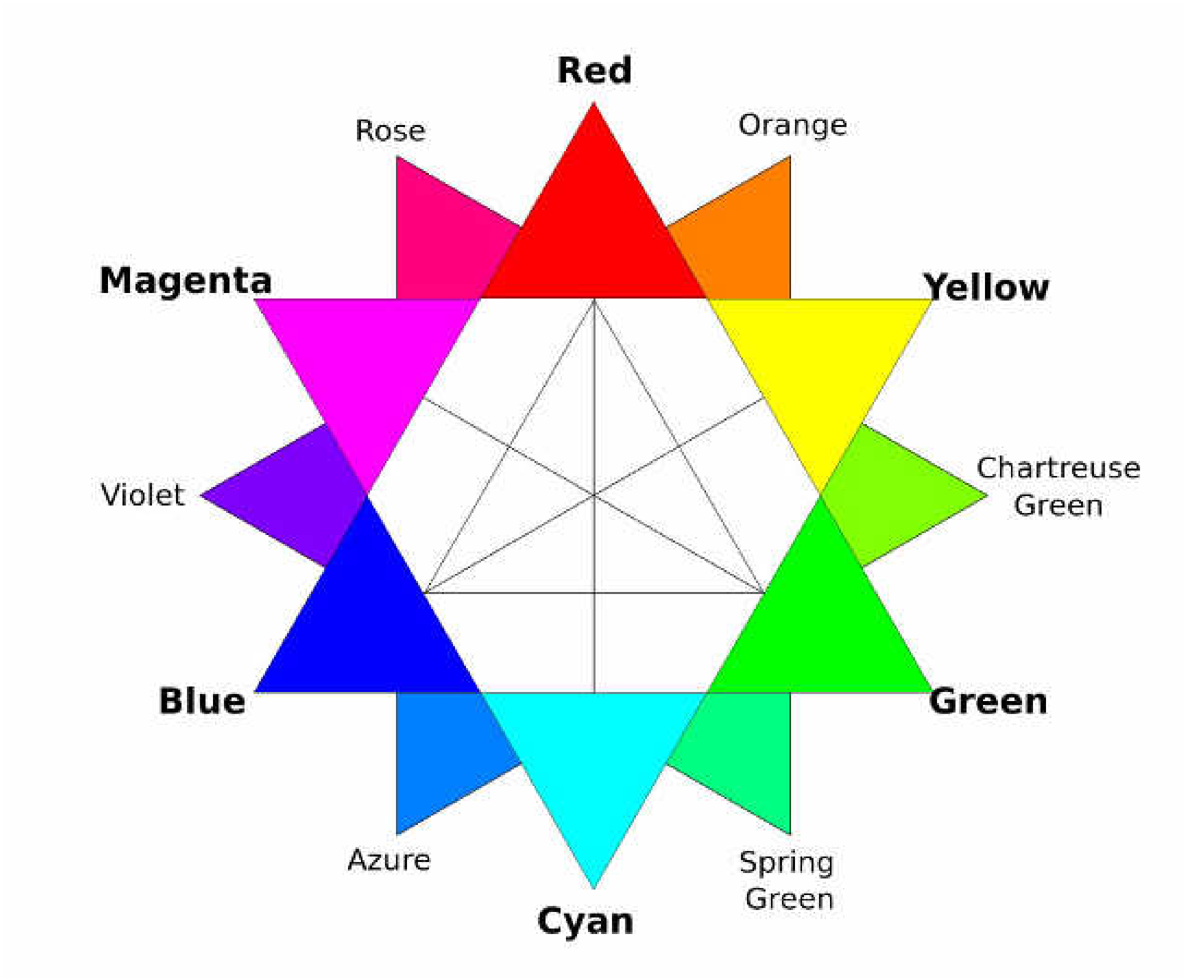


The Search for the Golden Fagus (Part 2)

by **Paul Edwards**



1. The TV (RGB) Colour System showing opposite Complementary Colours (from Wikimedia commons: File RBG colorwheel.svg)

The falling leaves drift by the window
The autumn leaves of red and gold
Autumn Leaves: Joseph Kosma & Johnny Mercer

Autumn Leaves of Red and Gold

The story I foreshadowed in Part 1 of this two part article starts in spring when the green leaves emerge and the process of photosynthesis commences in the chloroplasts. This involves the manufacture of carbohydrates using carbon dioxide from the air and water from the soil, powered by solar energy captured by the ‘antenna’ pigments, the green chlorophylls and the yellow carotenoids present in the leaves which act as solar panels (HyperPhysics Website, 2005).

The young foliage appears green because these two pigments respectively absorb the red and the blue components of sunlight, leaving the dominant complementary colour (green, from the colour wheel above) to be reflected back to the eye.

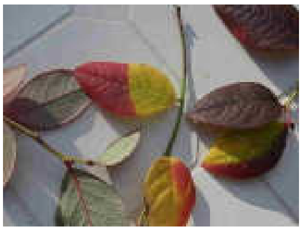
The Green Chlorophylls

The chlorophylls play a vital role in photosynthesis. Not only do they collect solar energy but they also supply the electrons that power the chemical reactions which produce the sugars, starches and cellulose needed by the growing plant. It might seem strange to introduce electrons into this biological scenario, seemingly far removed from physics and technology. However, electronic phenomena underlie all the physical and chemical processes that culminate in the reds and golds of autumn, in particular, oxidation (the loss of electrons from molecules), and reduction (their gain).
Unlike the stable carotenoids, the green chlorophylls are short-lived and need to be continually replenished by photosynthesis. However, as the days grow short, the chlorophylls fade away, leaving the carotenoids behind to colour the ageing foliage yellow.

The Gold Carotenoids

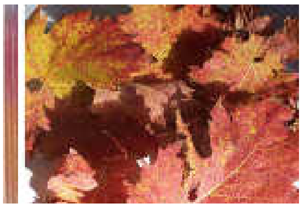
The carotenoid pigments, the yellow xanthophylls and orange carotenes, absorb light at the blue end of the spectrum. So, as the colour wheel indicates, they appear orange/yellow. The chlorophylls present in young foliage and unripe fruit usually mask these blue-complementary colours. The best known carotenoids are probably the orange carotenes in apricots and carrots, and the red lycopene in tomatoes. The yellow lutein is found in green leafy vegetables. Like the chlorophylls, the carotenoids are anti-oxidants, best known for their in-vitro antagonism to the carcinogenic free-radical oxidation products formed in animal cells. Carotenoid colours are utilised by birds and animals for signalling. They appear to serve two vital functions in green foliage. Besides assisting the chlorophylls to collect solar energy, they also protect them by absorbing potentially damaging blue and ultraviolet light.

The Red Anthocyanins


2. carotenoids & anthocyanins

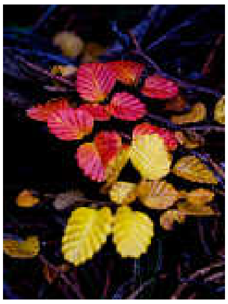
In some deciduous trees, including South American Nothofagus species, a third group of pigments appears in autumn. These are the anthocyanins, named for their blue colour when first isolated from cornflower petals. Unlike the carotenoids, the red, blue and purple anthocyanins are not usually present in young leaves but are photosynthesised from the sugars in the dying leaves. Their photosynthetic origin is evident from the blueberry leaf image, left. Note the shadowed (yellow) and illuminated (red/purple) upper leaf surfaces; the red anthocyanin-filled veins and the un-illuminated (green) lower leaf surfaces.

The water-soluble anthocyanins are commonly found in flowers, fruit, sap and roots and in the veins and vacuoles of autumn leaves. They usually absorb green or cyan light and consequently appear magenta or red, the corresponding complementary colours shown in the colour wheel. Anti-oxidants, like the carotenoids, are also



3. grape leaves

credited with health-giving properties. Anthocyanins readily change colour in chemical reactions. For example, red wine made from the Spanish Tempranillo grape variety typically has blue and purple hues owing to its high anthocyanin content and low acidity.



4. carotenoids and anthocyanins

The red anthocyanins probably act as a light screen, protecting against tissue-damaging blue sunlight in cold autumn conditions. Although the deep orange of late autumn Fagus may not be due to anthocyanins, the rare purple Fagus leaf colour in Dennis Harding’s photo in Part 1 and the magenta in Michael Gay’s photo, left, indicate their occasional presence. In the northern hemisphere cold, bright and dry autumn weather enhances red foliage: cold weather shuts off the flow of nutrients to and from the leaves; sunny weather enhances red because anthocyanins are themselves the products of photosynthesis; and dry weather concentrates the precursor sugars in the plant saps. These may be the conditions that produce occasional bright red/purple Fagus foliage. Abnormal light exposure may also affect anthocyanin physiology: an entire row of grapevine foliage is recently reported to have turned bright red following an autumn lightning strike.

Chemical analysis could settle the question of the autumn Fagus pigments. Simple paper chromatography techniques available in school science classrooms - and in the kitchen!—can separate the blue and purple anthocyanins from the yellow and orange carotenoids in late autumn leaves like the *Tempranillo* vine leaves below.

The Quantum Physics

Photosynthesis governs the birth, life and death of plants and their leaves. Electrons in the antenna pigment molecules capture and destroy light particles (photons) from the sun and snatch all their energy. This is the photoelectric effect, first explained in a famous paper written in 1905 by Albert Einstein.

In essence, the harvesting of sunlight energy by the molecular antennas in leaves requires a match between the energy of the incoming photons and the energies that can be absorbed by the electrons present in these molecules. Now the electrons which bind the carbon atoms together to form organic molecules behave like waves on a violin string—the longer the molecular string, the longer the electron wavelengths and the lower their corresponding energies. This violin string model of electrons in boxes earned Erwin Schrodinger the Nobel Prize for physics in 1933. It illustrates the famous Heisenberg Uncertainty Principle, named for another (1932) Nobel prize-winner, Werner Heisenberg.

Many molecular boxes are so small and their electrons are so energetic that they can only acquire energy from correspondingly high energy ultraviolet light photons. Consequently they don’t appear coloured, except perhaps to the birds and the bees. However, the xanthophyll molecules in yellow leaves each contain a line of 22 carbon atoms of just the right length to allow their electrons to resonate with and capture blue sunlight photons. The more complex green chlorophyll molecular rings absorb solar energy from red and blue light. The various antenna pigments are each tuned to capture photons of specific colours. If the antenna molecules were much shorter or longer, their vibrating electron waves could not resonate with solar photons of the visible spectrum and the leaves would lose both their colour and their effectiveness as solar energy collectors. In contrast, the palette of anthocyanin colours spans the entire spectrum as the molecular boxes containing their colour-giving electrons expand and contract with changes in the chemical environment—hence their extensive use by plants.

Carotenoid and anthocyanin based compounds are evidently vital to growing plants and animals, not just incidental contributors to passing shows of autumn colour like the golden Fagus.

Web References

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Captions

1 The TV (RGB) Colour System showing opposite Complementary Colours (from Wikimedia commons: File RBG colorwheel.svg)
2 Anthocyanin photo-synthesis in blueberry leaves. Canberra, June 2014.
3 Tempranillo grapevine leaves and a “kitchen sink” paper chromatogram of their anthocyanin (upper) and carotenoid (lower) pigments. (Kayena, Tasmania, May 2014).
4 Yellow carotenoids and magenta anthocyanins in the Fagus near Lake Fenton, Mt Field NP in 2008. (michaelgayphotography.com)

Page URL: https://www.disjunctnaturalists.com/articles2/golden-fagus-2.htm

Back to top